Effects of Runner Tip Size and Plugging Date on Fall Flowering in Short-Day Strawberry (*Fragaria* × *ananassa* Duch.) Cultivars

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ABSTRACT. Producing strawberry transplants from runner tips that were plugged ~1 month earlier (early July) than the standard time (early August) promoted fall flowering in some short-day strawberry cultivars. In 2002, 100% of 'Chandler' transplants produced in early July flowered in the fall, but none of the August-plugged 'Chandler' transplants flowered in the fall. In 2003, 73% of 'Chandler' transplants produced in mid-July from average-size runner tips and less than half of transplants from small-size runner tips flowered in the fall. Again, August-plugged plants did not flower in the fall. Flowering was absent in 'Northeaster' plants. Under protected cultivation, July-plugged 'Sweet Charlie' plants bloomed earlier and produced more fruit in November and December than those plugged in August. This study showed that fall flowering in 'Chandler' and 'Sweet Charlie' strawberry is possible if the transplants are prepared by plugging runner tips in early July. This novel technique for propagating strawberry transplants for annual plasticulture

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combined with production under high tunnels creates an opportunity for strawberry production in early winter and again in the spring (double cropping) in the mid-Atlantic coast region. doi:10.1300/J492v06n04_10

KEYWORDS. High tunnel, greenhouse, propagation, flower initiation, yield, season extension

INTRODUCTION

The main strawberry harvest season in the mid-Atlantic coast region (39°N, 77°W) is from early May to late June. Out-of-season fruit production in the region is very limited. Fruit of the day-neutral 'Seascape' harvested in November and December have been direct-marketed at US$3.00-4.00 per pound or about four times higher than fruit harvested in spring to restaurants in the Metropolitan Washington-Baltimore area (Takeda, unpublished). As a result, interest in out-of-season strawberry production systems has increased in the mid-Atlantic coast region (Durner, 1999; Takeda, 1999; Takeda et al., 2004, 2006; and Takeda and Hokanson, 2002, 2003). Containerized nursery (plug) plants and the annual plasticulture system has allowed several cultivars developed elsewhere (e.g., 'Chandler', 'Marmalada', 'Seascape' and 'Sweet Charlie') to be grown in the region. Planting of these cultivars using the plasticulture system has provided opportunities to extend the harvest season in the spring and make fruit harvesting more efficient in areas with prevailing mild winter climates (e.g., eastern North Carolina and Virginia). Short-day strawberry plants that will flower in the fall or shortly after planting in late August or early September would be desirable for the region. Innovative production technologies such as plasticulture, floating rowcovers, and high tunnels for environmental modifications are already available for extending the harvest season well into late December in the mid-Atlantic coast region (Fernandez and Ballington, 2003). Short-term cropping systems improve opportunities for farm diversification and help growers to produce a variety of fruit and vegetable crops for niche markets. Income from fall and spring fruit production (double cropping) can raise farm profitability.

Flower buds initiation in short-day strawberry cultivars starts in the shorter days of late summer to early spring whenever the temperatures are high enough (Darrow, 1966). Darrow (1966) noted that although short-day strawberry plants developed in the mid-Atlantic coast region can differentiate flower buds in the fall, anthesis does not occur in them in the fall because of less than ideal temperatures for reproductive development. Recently, Bodson and Verhoeven (2005) observed in the cv. 'Elsanta' that the first sign of inflorescence initiation started in October and carpel primordia initiated in November but they observed no further differentiation in the winter.

The physiological state of plug transplants and nursery conditions in which transplants are produced affect whether flower induction and inflorescence differentiation occur during the propagation phase or shortly after field establishment. Sonsteby and Hytonen (2005) and Verheul et al. (2006) reported that flower emergence and development in 'Korona' can be controlled by adjusting photoperiod, temperature, the duration of short-day treatment and plant age under greenhouse conditions. Fernandez and Ballington (2003) produced a moderate crop (175 g per plant) in the fall with conditioned 'Sweet Charlie' plants in the coastal region of North Carolina (USDA Hardiness Zone 7a). Their conditioning regime involved production of runner tips and transplants at a high elevation (~900 m above sea level) nursery in western North Carolina and 3 weeks of artificial short-day treatment. Durner (1999) reported that fruit production increased ~80 g per plant in January and February when 'Sweet Charlie' strawberry plug plants, 2-3 weeks old, were exposed in September to seven 9-h days without chilling (21°C day/21°C night, followed by seven 9-hour short days with chilling during the dark period (12°C night). In Japan, a technique described as an "extra early forcing culture" of cool night (13-14°C) and short-day (16-h dark) treatments for ~20 days or holding transplants at 17°C in the dark for 14 days in late summer is used to accelerate fall flowering (Oda, 1992). These treatments involve laborious daily movement of transplants in- and-out of cold rooms or dark rooms or the drawing of a black drop cloth over the plants for up to 3 weeks. The constraint to getting these preconditioning technique widely accepted has been the high production cost coupled with low productivity (Sonsteby et al., 2006). In Maryland, Takeda and Newell (2006) reported that fall flowering occurred in plants of the short-day 'Carmine' strawberry by simply advancing the plugging date of runner tips to early July for producing transplants used in annual plasticulture.

The objectives of this study were to determine the effect of tip size and plugging date of 'Chandler' and 'Northeaster' strawberry transplants on fall flowering and spring yield in an outdoor plasticulture system and the effect of plugging date and planting date of 'Sweet Charlie' transplants on early winter and spring fruit production in a high tunnel.

MATERIALS AND METHODS

Strawberry Cultivars

In 2002 and 2003, we used 'Chandler' strawberry, a 1983 University of California release (Voth and Bringhurst, 1984). 'Chandler' strawberry is the most widely used cultivar in the annual eastern production system outside Florida (Poling, 1993). In 2004, we evaluated 'Sweet Charlie' and 'Northeaster' strawberry. 'Sweet Charlie' strawberry is a short-day cultivar from the University of Florida (Chandler et al., 1997) that tends to produce fruit early (C.K. Chandler, University of Florida, personal communication). 'Northeaster' strawberry, a 1994 USDA release (Galletta et al., 1995), is an early-season cultivar developed for the traditional matted row production system. The source of plants for runner production and runner tips for plug plants, plugging dates, field planting dates and data collected in fall and spring are summarized in Table 1. Details of propagation methods and greenhouse growing conditions are provided elsewhere (Bish et al., 2001; Takeda and Hokanson, 2002, 2003; Takeda and Newell, 2006; Takeda et al., 2004, 2006).

In 2004, Davon Crest Farm, Hurlock, MD, provided runner tips of 'Sweet Charlie' strawberry on July 1, August 3 and 17. Tips were plugged into 50-cell packs containing Sunshine LC1 mix. The plug plants were mist sprinkled for 2 weeks in a greenhouse at the University of Maryland Wye Research and Education Center (WREC), Queenstown, MD, after which they were set outside the greenhouse until they were planted in raised beds prepared under a high tunnel in September (Table 1).

Field Production System

In all 3 years, strawberry transplants were established in the plasticulture system (Poling, 1993) at WREC. Information regarding the planting site and pre-plant preparation are given elsewhere (Takeda and Newell, 2006). Strawberry transplants were established in plasticulture system at WREC on September 10 in 2002, September 8 in 2003 and

TABLE 1. Runner tip source, cultivars tested, plugging and planting date, and field data collected in fall and spring for 2002-2003, 2003-2004, and 2004-2005 studies.

Source of plants	Cultivar	Plugging and planting dates	Fall data	Spring data
2002-2003 study: Commercial nursery, Hurlock, MD	'Chandler'	July 2 and September 10 August 8 and September 10	Plant survival Branch crown Runner number Percentage of plants with flowers	Total yield Fruit size Branch crown number
2003-2004 study: University of Maryland: College Park, MD and Salisbury, MD	'Chandler'	July 17 and September 8 August 13 and September 8	Plant survival Crown number Runner number Percentage of plants with flowers	Total yield Fruit size Branch crown number
2004-2005 study: USDA-ARS Kearneysville, WV	'Northeaster'	July 3 and September 1 August 5-6 and September 1	Crown number Runner number Percentage of plants with flowers Marketable yield	Marketable yield
Commercial nursery, Hurlock MD	'Sweet Charlie'	July 1 and September 13 August 3 and September 13 August 17 and September 21		Marketable yield

September 1 in 2004. Planting dates approximated the recommended transplanting for this region. The plants were arranged in offset double row spaced 30 cm between and in rows with 10-plant plots. Plots were randomized in a complete block design with four replications for each cultivar/treatment. Plots were irrigated by overhead micro-sprinklers for 2 days during establishment.

High Tunnel Production

For high tunnel production studies in 2004, we used a 29.5-m long × 9.1-m wide high tunnel (Ledgewood Farm Greenhouse Frames, Moultonboro, NH), constructed in 2003 at WREC. Plants and plastic mulch from the 2003-2004 production cycle were pulled out on July 16, 2004, and the ground was roto-tilled deeply. Fertilizer (16-8-8) was incorporated into

soil by shallow tillage at the rate of 450 kg·ha^{-1}. Crowned beds (10 cm high and 43 cm wide) were formed with a bed shaper at 1.25 m spacing between row middles, a drip irrigation tube with discharge rate of 1.7 l·min^{-1}·(30.5 m)$^{-1}$ was placed off-center on each bed. Beds were covered with black polyethylene mulch. Strawberry transplants were hand-planted in the middle of each raised bed at 30-cm intervals. On September 13, 2004, 'Sweet Charlie' transplants that were started on July 1 and August 3 were set in the ground. On September 21, transplants started on August 17 were set in the ground. Twenty transplants were set in each plot. Plots were irrigated with micro-sprinklers for 2 days. Transplants received a post-transplant application of starter fertilizer (20-20-20) at 1 kg·(380 l)$^{-1}$ water. Fungicides, insecticide and drip irrigation were applied as needed. There were four replications consisting of a combination of plugging and planting dates.

Field Performance Data Collection

In 2002, the following data were collected on November 14 in each plot: number of surviving plants, number of plants with flowers and fruit, and runner and branch crown number (only for three plants per plot). Runners, flowers and fruit were discarded. In fall 2003, runner, crown, and flower/fruit development was determined on December 10 as previously detailed for year 2002, except runner and branch crown numbers were recorded for all 10 plants in the plot. In fall 2004, data on runner and branch crown number for each plant and number of plants with flowers and fruit in each plot were recorded on November 3 after which all runners were detached by hand. On November 18, we detached and counted flower buds, flowers, and green and red fruit, and weighed large fruit.

'Sweet Charlie' strawberry plants grown in a high tunnel were harvested on November 12 and 24, and December 7 and 21, 2004. At each harvest, data were collected for plot yield and number of fruit harvested.

In spring 2003, 2004 and 2005, we harvested ripe strawberries twice weekly from mid-May to mid-June in field plots. In spring 2005, plots of 'Sweet Charlie' strawberry inside the tunnel were harvested twice weekly from late March to June. Each fruit was graded as marketable or cull, and weighed. Individual plant yield for the season was calculated.

Statistical Analysis

Analysis of variance (ANOVA) for treatment and cultivar was carried out using PROC GLM of SAS (2001). Calculated percentage values were arcsin transformed prior to imposing statistical analysis. Means separations were determined using the DIFF option for all contrast ($P \leq 0.05$).

RESULTS

2002-2003 and 2003-2004 Studies

Post-establishment plant loss was minimal in 2002 and 2003 (Table 2). All the July-plugged 'Chandler' transplants had produced flowers by mid-November while none of the August-plugged transplants had (Table 2). Branch crown development was greater in the early July-plugged transplants than in the early August-plugged transplants, 2.3 versus 1.2 per plant, respectively. Runner production was rather low in all treatments. In the 2003 study, 73% of the July-plugged transplants had flowered by November, but fall bloom was not observed in the August-plugged transplants (Table 2). None of the transplants obtained from a commercial nursery flowered in the fall (data not presented). Since the plants were in the open culture system, fruit were injured by frost and none reached the stage for harvesting in fall of 2002 and 2003. The plugging date of July 17 for 2003 season was 2 weeks later than in the previous year. The delay in plugging may have been a factor in that only 73% of the July-plugged 'Chandler' plants producing flowers in the fall.

In spring 2003, fruit was harvested for 4 weeks. Yield per plant was 704 g for the July-plugged transplants and ~560 g for the August-plugged transplants ($P = 0.082$). These yields are equivalent to ~29.6 and 23.5 metric t ha^{-1} based on the ~42,000 transplants ha^{-1} planting density and are far better than those reported for annual plasticulture studies conducted in New Jersey (Fiola et al., 1995), and slightly higher than those obtained in commercial fields in North Carolina (Poling, 1993). Total marketable yields obtained in our 2003-2004 study were ~25 metric t ha^{-1} across treatments. The tonnage approached those yields obtained from 'Chandler' plants in a field study conducted near Raleigh, NC (USDA Plant Hardiness Zone 7b) during 1986-1987 season (Poling, 1993). Average fruit size for the season was similar with 23 and 24 g per fruit for the July- and August-plugged treatments, respectively. By the end of the harvest period in June, July-plugged plants possessed one

TABLE 2. Effects of plugging date and runner tip size on plant development in 'Chandler' strawberry in fall 2002 and 2003 and spring crop in 2003 and 2004.

Plugging date	tip size	Fall flowering plants[x] (%)		Branch crowns in fall[x] (no./plant)		Runnering in fall[x] (no./plant)		Spring crop yield fruit size (g/plant) (g/fruit)				Branch crowns in spring (no./plant)	
		2002	2003	2002	2003	2002	2003	2003	2004	2003	2004	2003	2004
July	Average	100a[y]	73a	2.2a	2.1a	1.8b	3.4a	704a	647a	21.1a	18.1a	5.4a	4.9a
	Small[z]	–	41b	–	1.8a	–	2.8a	–	632a	–	18.0a	–	4.8a
August	Average	0b	0c	1.0b	2.0a	3.4a	2.0b	559b	602a	22.5a	18.3a	4.3b	5.2a
	Small	0b	0c	1.0b	1.8a	2.4b	2.1b	556b	590a	23.9a	18.0a	4.5b	4.6a

[x]Fall growth measurements were taken on November 14, 2002 and on December 10, 2003.

[y]Values in columns followed by the same letters are not significantly different ($P = 0.05$). Mean separation performed by DIFF option of SAS Proc.

[z]Small runner tips were not included in the 2002-2003 study.

more branch crown than those plugged in August (P = 0.008). In 2004, fruit was harvested for 2 weeks from May 10 to May 25. Yield per plant was between 600 and 650 g, average fruit weight was ~18 g and branch crown numbers averaged about five on each plant across the treatments (not significantly different at P = 0.05; Table 2).

2004-2005 Study

None of the 'Northeaster' plants flowered in the fall (Table 3). In the field, runner production was less than two per plant in 'Northeaster' plants (Table 3). These runner numbers were lower than in a previous study in which five runners were produced on the July-plugged 'Northeaster' transplants that were established in plasticulture on August 12 at Beltsville, MD (Hokanson et al., 2004). These results agree with findings of Poling (1993) that containerized strawberry plants established in the annual plasticulture system in mid-to-late summer (August) tend to produce more runners in fall than those established in early fall (September). In spring 2005, 'Northeaster' was harvested from May 12 to June 7 totaling eight pickings. There was no effect of runner tip size on spring marketable yield or fruit size (average fruit weight of 17 g across all treatments). The lowest marketable yield (646 g per plant) was noted in plants propagated in August from small tips (Table 3).

In the high tunnel study, we harvested fruit from 'Sweet Charlie' strawberry in November and December and again starting in late March

TABLE 3. The effect of plugging date and runner tip size of 'Northeaster' strawberry on fall branch crown, runner production and flowering, and fruit production in spring.*

Plugging date	Tip size	Fall branch crown development (no./plant)	Fall runners production (no./plant)	Plants with inflorescences in fall (%)	Spring crop (g/plant)
Early July	Average	3.8a[z]	1.2b	0a	873a
	Small	3.3b	1.1b	0a	781a
Early August	Average	2.5c	2.2a	0a	699a
	Small	1.8d	1.3b	0a	646a

*All transplants were established on September 2, 2004 in outdoor plasticulture at the Wye Research and Extension Center, Queenstown, MD (fall growth measurements were collected on November 3, 2004).
[z]Values in columns followed by the same letters are not significantly different ($P = 0.05$). Mean separation performed by DIFF option of SAS Proc.

for ~13 weeks. The plants that were plugged in early July and established in mid-September produced twice as much fruit in November and December as did August-plugged plants that were established in mid- or late September (Table 4). Planting date closer to September 1 or even in late August may provide greater yields in the fall in colder climatic areas (USDA Plant Hardiness Zones 7a and 6b) (Fiola et al., 1995; O'Dell and Williams, 2000). In the spring, July-plugged plants produced significantly more fruit than plants plugged in August (Table 4).

DISCUSSION

There is an optimal planting date for each cultivar recommended for the plasticulture in the region (Fiola et al., 1995; O'Dell and Williams, 2000). Transplants that are field planted late produce less fruit in spring (Fiola et al., 1995; O'Dell and Williams, 2000; Takeda and Hokanson, 2002). Takeda and Newell (2006) suggested that spring yield was related to branch crown development in the fall. Earlier planting dates provide more days in the fall for plant growth. However, if plantings occur too early then plants may grow excessively and more runners may appear in the fall (Poling, 1993). In our study, the growing conditions under the high tunnel in December appeared to be satisfactory for plant growth since 'Sweet Charlie' plants were still producing flowers in late December.

Other researchers have described 'conditioning' treatments for plug plants such as exposure to specific high and low temperatures (Bish et al.,

TABLE 4. Effects of transplant preparation method on fruit production during November and December 2004 and spring 2005 in 'Sweet Charlie' strawberry plants in a high tunnel at the Wye Research and Education Center, Queenstown, MD.

Treatment plugging time	Planting date	Early winter marketable yield (g/plant)		Spring crop (g/plant)
		November	December	
Early (July 1)	September 13	21a[z]	35a	482a
Standard (August 3)	September 13	2b	18b	307b
Late (August 17)	September 21	0b	20b	218b

[z]Values in columns followed by the same letters are not significantly different ($P = 0.05$). Mean separation performed by DIFF option of SAS Proc. Mixed.

2004), low temperatures and short-day photoperiod (Durner, 1999; Heide, 1977; Hytonen et al., 2004; Oda, 1992; Verheul et al., 2006) to force short-day strawberry transplants to flower shortly after establishment in out-of-season production systems. The earliest flowering that Verheul et al. (2006) observed in an 8-week-old 'Korona' transplant was at ~48 days after completion of the treatment. The difference in the number of days to flowering clearly demonstrates that the sensitivity of the strawberry plants to photoperiod and/or temperature and varies with cultivar, plant material, and their age. We have developed a simple protocol that does not need cold temperature exposure or photoperiodic modifications to force short-day cultivars to flower under outdoor conditions in the fall in Maryland. Fall flowering occurred in high percentage of transplants from runner tips harvested and plugged in early July, maintained in the greenhouse for ~8 weeks, and then field planted in early September. Using this cropping system, we found that 'Chandler' and 'Sweet Charlie' strawberry would flower shortly after field establishment and produced ripe fruit as soon as 2 months after planting.

The critical components for producing strawberries in the fall in the mid-Atlantic coast region with short-day cultivars are as follows: (1) use of cultivars developed primarily for areas with mild winter climates, (2) preparation of containerized transplants in early July, (3) field establishment of transplants around September 1 or slightly earlier, and (4) season extension with protected cultivation techniques. Even with early July-plugged transplants, if field planting occurs in mid-September or later, the prospect of harvesting ripe fruit in November and December is significantly reduced (Table 4). Fall fruit production was negligible in 'Chandler' plants that were started from runner tips harvested in early July, cold-stored for 4 weeks at 2°C, plugged into cell packs in early August, and field transplanted in early September or from ~4-week-old 'Chandler' transplants obtained from a local strawberry transplant producer (Takeda et al., 2006). Our findings suggest that fall fruit production is unlikely from transplants produced by the conventional strawberry plug transplanting technology, for example, transplanting plug plants, that were 3.5-5 weeks old, produce in 48- or 50-cell packs in early September. In addition, it was not possible for the short-day cv. 'Northeaster' that was developed for areas with severe winter climates to flower in the fall. Fall environmental conditions in the mid-Atlantic coast region are not adequate for promoting flower bud formation or out-of-season bloom in northern cultivars or those developed for areas with cold winters (Darrow, 1966). For example, in winter fruit production studies conducted in a heated greenhouse with supplemental lighting

(Takeda et al., 1999), the earliest harvest occurred in February for fall-established 'Primetime' and 'Delmarvel', two cultivars released by USDA-Beltsville, MD, but as early as December for the short-day cv. 'Camarosa' that was developed in California with mild winter climates.

The origin or source of plants for generating plug plants, growing conditions for plug transplants, and field establishment date used in this study varied from year to year, but the results of our studies clearly showed that at least for 'Sweet Charlie' and 'Chandler' strawberries the time of runner tip harvest and plugging had a profound effect on fall flower production. This modification in plug-plant production technique for producing transplants offers opportunities for strawberry growers in the mid-South, mid-Atlantic coast regions and other areas with cool fall climates to double-crop short-day strawberry cultivars in late fall and in spring. Transplants of short-day cultivars 'Chandler' (Table 2), 'Sweet Charlie' (Table 4) and 'Carmine' (Takeda and Newell, 2006) strawberries that were propagated in early July and established in the field in early September respond to natural photoperiodic induction (long nights) for reproductive development. At the test site in Queenstown, MD (latitude 39°N), daily dark period increases to > 10 hours around September 1. Temperatures in September and October are generally sufficient for July-propagated plants to complete floral bud differentiation shortly after field establishment and subsequently flower around October 1 and produce harvestable fruit by early November.

CONCLUSIONS

Our studies demonstrated that fall flowering in 'Chandler' and 'Sweet Charlie' strawberry is inducible by advancing the plugging date to early July. As Bish et al. (2004), Fernandez and Ballington (2003) and Verheul et al. (2006) showed, short-day cultivars can be induced to flower early by growing transplants in artificial, short-day and cool temperature conditions in late summer. However, the cost of the equipment and the energy needed to condition transplants by these methods for floral induction are high. Our method for promoting fall flowering in some short-day cultivars appears to be more practical and does not require artificial lighting or cooling. Transplants produced by this method are ~8-weeks-old by the time they are established in the field. Commercial plug-plant propagators prefer to deliver ~4-week-old transplants to growers (D. Lankford, Hurlock, MD, personal communication). An earlier tip harvesting time and additional time in the nursery would cer-

tainly increase cost of producing transplants, but this new planting material allows growers in the mid-Atlantic coast region to double-crop short-day strawberries in high tunnels.

The potential strawberry yield in the fall and early winter under protected cultivation can increase income. There are several methods to obtain fall fruit production in the mid-Atlantic coast region. Dormant day-neutral 'Seascape' strawberries planted in late spring and de-flowered for 2 months produce some fruit as early as September (T. Nourse, South Deerfield, MA, personal communication). Cold-stored waiting bed plants and module or tray plants are used in Europe for autumn cropping on substrate culture (Lieten et al., 2005). In our study, the transplants plugged early in July grew in the greenhouse until the first week in September under environmental conditions generally considered not favorable for floral induction (e.g., long days and temperatures > 21°C during day and night). However, they began flowering in ~40 days after planting in the field under natural short-days and chilling temperatures at night. It is possible to grow tray transplants after they are rooted outside the greenhouse until field establishment as we have shown with 'Sweet Charlie' transplants in the 2004-2005 study and still have transplants that will flower in October and November. Our studies also confirmed as others (e.g., Fernandez and Ballington, 2003) have shown that high tunnels are useful for extending the production season. 'Sweet Charlie' strawberry under a tunnel produced a small crop in November and December and the main spring crop starting in late March for ~12 weeks. In contrast, 'Sweet Charlie' plants in outdoor plasticulture did not have harvestable fruit until early May and harvest ran for only several weeks. We will determine whether transplants of other short-day cultivars (e.g., cvs. 'Camarosa', 'Darselect', 'Raritan' and 'Ventana') can be induced to flower in fall by advancing the time of propagation to early July. The goal is to increase our understanding of the physiological control of flowering and create environmental conditions for improving the cropping potential of short-day strawberry cultivars in fall and out-of-season.

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